EGU22-8824, updated on 19 Aug 2022
https://doi.org/10.5194/egusphere-egu22-8824
EGU General Assembly 2022

Importance of accurate numerical implementaion of electron inertial terms in hybrid-kinetic simulations of collisionless plasma turbulence

Neeraj Jain[2], Patricio A. Muñoz[1,2], Jörg Büchner[1,2], Meisam Tabriz[3], and Markus Rampp[3]
[1]Max Planck Institute for Solar System Research, 37077 Goettingen, Germany
[2]Center for Astronomy and Astrophysics, Technical University Berlin, 10623 Berlin, Germany (neeraj.jain@tu-berlin.de)
[3]Max Planck Computing and Data Facility, 85748 Garching, Germany

A comprehensive understanding of the turbulent dissipation of magnetic energy in collisionless space and astrophysical plasmas, an unsolved problem yet, requires efficient kinetic simulations of collisionless plasma turbulence. Fully kinetic simulations (where all the plasma species, ions and electrons, are treated kinetically) of collisionless plasma turbulence covering a full range of kinetic scales (from ion to electron scales) are computationally demanding. Hybrid-kinetic simulations (ions treated as kinetic species and electrons as fluid and therefore ignoring electron kinetic effects) with inertia-less electron fluid, although less demanding computationally, can not address the physics at the electron scales. Hybrid-kinetic simulations with inertial electron fluid are applicable all the way down to electron scales (still ignoring electron kinetic effects) with computational demands in between those for hybrid-kinetic simulations with inertia-less electron fluid and fully kinetic simulations, and, therefore have begun to attract significant interest recently.

The majority of hybrid-kinetic codes, solving either the Vlasov equation for the ions by an Eulerian method (called Vlasov-hybrid codes) or the equations of motion for ion macro-particles by the Lagrangian Particle-in-Cell (PIC) method (called PIC-hybrid codes), numerically implement the electron inertial terms of the electron fluid equations under varying approximations which are not necessarily valid at electron scales. In hybrid-kinetic codes, electric field is calculated from either the generalized Ohm's law or an elliptic partial differential equation. In the former case, the non-stationary electron inertial term (time derivative of electron bulk velocity) in the generalized Ohm's law is neglected (approximation A1). In the latter case, a part of the electron inertial term involving cross partial derivatives of electric field is neglected in comparison to the other part involving second order partial derivatives to obtain a simpler elliptic partial differential equation for electric field (approximation A2). For two dimensional collisionless plasma turbulence, we assess the validity of the two approximations of electron inertial terms used in hybrid-kinetic codes for the calculation of electric field. We employ our recently parallelized three-dimensional PIC-hybrid code CHIEF, which numerically implements the electron inertial terms without any of these approximations, in a quasi-two dimensional setup for the simulations of collisionless plasma turbulence. We find that the approximation A1 impacts the accuracy of the results at the electron scales and therefore may lead to physically incorrect results. Approximation A2, on the other

hand, is found to be invalid from ion to electron scales. We conclude that the simulation results obtained using the hybrid-kinetic codes with an approximate numerical implementation of the electron inertial term need to be interpreted with caution.